

EVALUATION
OF
IMPACTS OF STORM WATER RUNOFF
AND COMBINED SEWER OVERFLOWS
ON RECEIVING WATERS

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EVALUATION
OF
IMPACTS OF STORM WATER RUNOFF
AND COMBINED SEWER OVERFLOWS
ON RECEIVING WATERS

A Technical Memorandum

Prepared for
Working Group II

Toronto, June 1979

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INTRODUCTION

Precipitation becomes contaminated as it falls on and passes through urban areas. The first degradation comes from contact with pollutants in the air; the next, through contacts with contaminated ground surfaces; and finally, through scouring of residues or mixing with sanitary sewage in sewer systems.

Urban surface runoff, either collected separately or coming as nonsewered runoff, and combined sewer overflows will eventually empty their pollution loadings into some receiving body of water. The discharged pollutants will decompose, accumulate or be passed on downstream using the receiving water as a carrier (Metcalf and Eddy, 1971).

In the past, efforts to control water pollution were focused on point sources of pollution, such as wastewater and industrial effluents. This was because point sources were obvious in nature and easy to identify. During this decade, however, the detrimental effects of urban nonpoint sources of pollution on the quality of receiving waters are becoming apparent. Hence, the control and treatment of stormwater runoff and combined sewer overflows from urban areas are problems of increasing importance in the field of water quality management.

Water quality planning and water pollution abatement programs may need in the near future to be based on an analysis of the total urban pollution load from point and nonpoint sources. An appreciation of the impacts of urban runoff on receiving waters and an acquaintance with available assessment techniques will be useful to meet these goals.

WATER QUALITY CHARACTERISTICS OF STORM WATER RUNOFF

Stormwater runoff is the excess precipitation which exceeds the detention storage and the infiltration capacity of the urban surface

and finds its way to the nearest man-made or natural channel. The major groups of pollutants carried by stormwater runoff are suspended solids, oxygen demanding substances (chemical oxygen demand and biochemical oxygen demand), nutrients (phosphorus and nitrogen), trace metals and arsenic (Pb, Zn, Cd, Cr, Cu, Fe, Ni, Hg, Sr, and As), organic chemicals (oils, grease, phenols, PCBs and pesticides), salts, asbestos and bacteria (Jeffs, 1977).

The most important contributor of pollutants to stormwater runoff are the streets and gutters directly connected to storm sewers. Pollutants accumulate on them from vehicular and industrial emissions and leakages, atmospheric fallout, street litter, animal droppings, deciduous leaves, road deicing, and construction activities.

The rate of buildup of pollutants in urban areas is dependent on the type of land use; being higher for commercial and industrial areas and lower for residential and open space areas. Table 1 gives the rate of dry weather pollutant buildup on urban watersheds based on data from Chicago and Tulsa, U.S.A. and Burlington, Ontario, Canada (Marsalek, 1977).

The concentrations of pollutants in stormwater runoff vary significantly during runoff events. The runoff picks up accumulated sediments, nutrients, metals, and other pollutants and transports them into the stormwater receiving system, often with the highest concentrations occurring on the rising limb of the runoff hydrograph. This phenomenon is called the first flush and has been reported by Weibel et al (1964), Colston (1974), Shaheen (1975), Weatherbe and Marsalek (1978). It should be noted, however, that a first flush does not always occur, its absence is affected by such variables as the nature of the storm, antecedent conditions, and the transport system for runoff (Dunbar and Henry, 1966; Poertner, 1976; and Singer and So, 1979).

Table 1.

RATE OF DRY WEATHER POLLUTANT BUILDUP ON URBAN WATERSHEDS (Marsalek, 1977)

Land Use	AVERAGE LOAD IN LBS PER DRY DAY PER MILE OF STREET										
	BOD		COD			N			PO ₄		
	Chicago Tulsa		Burlington Chicago Tulsa			Burlington Chicago Tulsa **** **			Burlington Chicago Tulsa ***** ***		
Single Family Residential*	.36	1.98	3.91	2.95	13.9	.165	.03	.14	.027	.004	.18
Multiple Family Residential*	.87	1.98	--	9.70	13.9	--	.15	.14	--	.012	.18
Commercial	2.70	3.06	--	13.6	20.3	--	.14	.23	--	.024	.24
Industrial	1.45	3.51	--	--	27.7	--	--	.26	--	--	.57

* The Tulsa data do not distinguish between single family and multiple family residential.

** Organic Kjeldahl Nitrogen

*** Soluble Orthophosphate

**** Nitrates and Nitrites

***** Total Phosphorus

Pollutant concentrations as reported in various urban studies in Ontario have been summarized by Weatherbe and Novak (1978). Table 2 gives the range of pollutant concentrations in stormwater runoff and combined sewer overflows based on Ontario data. The table indicates extremely wide ranges of variation in concentrations with the high values exceeding those encountered in raw sewage. These extremes, however, are of short duration and do not reflect the total loadings contributed by stormwater runoff.

Table 2. RANGE OF POLLUTANT CONCENTRATIONS IN STORMWATER AND COMBINED SEWER OVERFLOWS (Weatherbe and Novak, 1977)

	C O N C E N T R A T I O N (mg/litre)						
	BOD	COD	SS	Pb	N-Kjel.	NO ₂ +NO ₃	P-Tot.
Stormwater	1-630	5-1090	2-4122	0.02-1.8	0.2-20	0.2-9.6	.04-11.0
Combined Sewer Overflows	4-1730	25-2000	6-7700	0.01-4.8	1.8-26	0.1-2.8	.2 -28.0

WATER QUALITY CHARACTERISTICS OF COMBINED SEWER OVERFLOWS

The wastewater produced in urban areas from domestic, commercial and industrial sources is commonly referred to as dry weather flow (DWF). It is the practice in Ontario to convey DWF either in a pipe system that excludes storm waters (separate sewer system) or in a system that includes storm waters (combined sewer system).

It is almost a universal practice to treat DWF prior to its release to receiving waters regardless of the method of conveyance. In combined sewer systems this is done by means of a regulatory device which diverts all flows during dry periods. During rain or snowmelt, the flows arriving at the regulator may be far in excess of the available storage and treatment capacities. This excess is bypassed directly to the receiving waters without treatment and is called the combined sewer overflow.

Based on the above, combined sewer overflows consist of a mixture of raw sewage, storm water and such residue as may be picked up in the conveyance system due to scouring. The water quality characteristics of combined sewer overflows vary greatly from one community to another according to relative amounts of sewage and surface runoff, the amount of solids deposited during dry periods and scoured in storm periods and the size of the interceptor. Table 2 shows the range of pollutant concentrations as measured in Ontario communities.

A comparison between the average compositions of raw sewage, treated sewage (primary and secondary), combined sewer overflows and surface urban runoff is given in Table 3 (Waller and Novak, 1979).

IMPACTS OF STORM WATER RUNOFF AND COMBINED SEWER OVERFLOWS ON RECEIVING WATERS

Untreated stormwater runoff and combined sewer overflows may contribute a significant portion of the total pollution load entering receiving waters on an annual basis, and are often significant on a shock-load basis during wet events. These facts are especially important when large sums of money are spent to treat the domestic wastewater without proper recognition of urban runoff impacts.

When pollutants from urban runoff are discharged into receiving waters, they affect the water quality in several ways. Some of these effects are immediate such as bacteria contamination. Others are long-term effects such as nutrient enrichment which may lead to eutrophication.

Receiving waters such as streams, lakes and estuaries differ in the manner in which they react to similar pollutant loadings. Further, the types, extents and rates of water quality processes that occur in water bodies are controlled by the immediate physical environment as defined by climate and physiography. For example, one of

Table 3.

COMPOSITION OF SEWAGE AND STORM WATER
(After Waller and Novak, 1979)

	BOD mg/l	SS mg/l	Total N mg/l	Total P mg/l	Coliform per 100 ml	Fecal ^(3,4) Coliform per 100 ml
Raw Sewage (1)	160	220	28	6.4	10^8	10^7
Treated Sewage (1)						
- Primary	54	54	21	2.4	10^7	10^6
- Secondary	18	30	13	1.5	10^4	10^3
Combined Sewer Overflow (2)	40	222	8.0	1.6	10^7	10^6
Surface Runoff	13	200	3.5	0.5	2×10^4	5×10^3

Notes: (1) Measured flow-weighted mean from Ontario MOE reports.

(2) Calculated flow-weighted mean for Ontario Great Lakes communities.

(3) These values are representative of values recorded in Canadian and U.S. communities.

(4) Note - Ontario Total Body Contact Recreational Standards:

Total Coliform 10^3 per 100 ml.

Fecal Coliform 10^2 per 100 ml.

the unique characteristics of a river is that the water column is continually subjected to a new benthic or attached biotic community by virtue of the fact that the water column continually moves downstream. This system is much different from lakes where overlying water column remains in contact with the same benthic community in a given location. If the intensity of the pollution is not too great and the duration is not too long, the benthic community in the river will be relatively unaffected by the movement of the pollutant through the system. On the other hand, the plankton will be directly affected by the wasteload, since they will tend to move downstream with it. The reaction of these biota to the pollutant load depends on the initial concentrations of the pollutants and the length of time it takes before the processes of dispersion or biological decay can reduce concentrations to acceptable limits (Roesner, 1979)

The response of a receiving water to an introduced wasteload depends also on its initial state. Thus, the particular response of the receiver under different initial states is basically a matter of defining the appropriate boundary conditions at the time the wasteload is imposed.

In addition, the loadings and the types of pollutants contributed by urban runoff are important from the viewpoint of impact on receiving waters. Definition of pollutant loadings from an urban watershed requires intensive collection of data on precipitation, runoff, quality and physical characteristics of the watershed.

All the above considerations indicate that the question of impacts of urban runoff on receiving waters is an issue which is dependent on local specific conditions. It is not surprising therefore to find that much of the current literature advocates the need for individual examinations on a city-by-city basis of the impacts of urban runoff on receiving waters. It will be useful, however, to describe the impacts of urban runoff on receiving waters in terms of major pollutants (oxygen demanding materials, suspended solids and associated contaminants, nutrients, heavy metals and bacteria) and to cite a few examples from various urban studies carried out in Canada and U.S.A.

Oxygen Demanding Materials

The dissolved oxygen concentration (DO) is one of the most important water quality parameters which is used to evaluate the impact of oxygen demanding materials on receiving waters. Oxygen demanding materials contributed by urban runoff may pose a serious problem to receiving waters. For example, under conditions of low flows, high temperatures and point source discharges the initial DO levels in a stream tend to be low. As urban runoff from a storm event begins to enter the stream, the effects of increased flow tend to drive the DO concentration up. Downstream from the urban area, however, the oxygen demanding materials washed into the stream begin to exert themselves and an oxygen sag of varying magnitude and duration develops. Rimer and Nisse (1978) found that the stormwater runoff generally depressed the DO level in the Neuse River below the low flow antecedent level by about 1 mg/l and generally for less than one day. Pitt and Amy (1973) reported that the immediate toxic effects of urban runoff are most likely due to extreme oxygen demand and, in a simulation, showed that approximately two-thirds of the BOD was exerted during the first day after runoff. Colston (1974) concluded in his Durham, N.C. study that 40-50 per cent of the chemical oxygen demand in urban runoff was susceptible to biodegradation in 20 days. Clarke et al (1978) investigated the impacts of the pollutant loadings to Kettle Creek, Ontario from the St. Thomas pollution control plant and the City's storm drainage system. The effects of these effluents on the DO levels in the Creek were considered. It was found that the wet and dry weather conditions were equally severe as both resulted in a large number of violations annually. The evaluation was based on the MOE criteria of 5 mg/l of DO for 95 per cent of the time in a given month with allowable concentrations as low as 4 mg/l for short periods in any one day.

As part of the Grand River Basin Water Management Study continuous monitoring of DO variations were made since 1975 at three stations located on the Speed River. The first station is located

immediately below the City of Guelph; the second about 5 km below the City and the third above the confluence with the Grand River. Point and nonpoint sources of pollution have caused excessive algal blooms within this section of Speed River. Under conditions of low flows and high temperatures, the photosynthesis and respiration processes associated with the algal blooms cause the DO regime in the river to exhibit extremely high DO levels during the day and extremely low levels during the night. A preliminary examination of records collected at the three stations indicates that during rainfall events the DO regime is affected for a period of two to three days. The records show that immediately after a storm event the maximum DO levels tend to be lower and the minimum levels higher than observed during dry weather flow. The observed smaller ranges of DO variations after storm events could be the net outcome of several factors influencing the system at the same time. On one hand, during storm events higher flows will flush away some attached algae and cloudy skies and turbid flows will reduce light availability to aquatic plants. These conditions will result in reduced photosynthetic processes and decreased oxygen production. On the other hand, increased flows and decreased algae will result in reduced respiration processes and decreased oxygen consumption. No oxygen sag due to exertion of oxygen demanding materials was observed below the City of Guelph. This is due perhaps to the fact that the time of travel from the City to confluence is short and does not allow for the development of such a sag.

Pitt and Field (1977) investigated the potential impact of urban runoff on receiving streams. Their analysis assumes a hypothetical city with the following characteristics:

Population	= 100,00 people
Total land area	= 50 km ²
Curb length	= 1300 km
Sweeping frequency	= once every five days
Sanitary sewage flow	= 0.525 m ³ /s
Urban runoff pollutant loadings (total solids)	= 44 kg/curb-km/day
Uncontaminated receiving water flow	= 2.80 m ³ /s

The study also assumed that the sanitary sewage has the following characteristic after secondary treatment:

Suspended solids	= 30 mg/l
COD	= 30 mg/l
BOD	= 26 mg/l
P	= 0.6 mg/l
TKN	= 4.8 mg/l

Oxygen sag curves were determined for the hypothetical case. They were computed to show oxygen depletion caused by the secondary treated sewage only and by the secondary treated sewage and untreated urban runoff. When urban runoff effects were considered, the receiving water flows were increased to include urban runoff volume. Pitt and Field found that if the DO level of the receiving water in this hypothetical case is to remain greater than 5 mg/l to meet receiving water standards, then the allowable discharge of BOD in the urban runoff must be kept less than 3300 kg. This amount is equivalent to the pollutant accumulation on streets during one day. If the BOD discharge is 16000 kg, the DO in the receiving water could be below 5 mg/l for a distance equivalent to about eleven days flow downstream (Figures 1, 2 and 3).

Suspended Solids and Associated Contaminants

Urban runoff may be described as having suspended solids concentrations higher than or equal to those of raw sewage. The sources of suspended solids are erosion, emissions from motor vehicles, atmospheric fallout and construction activities. Many studies revealed that the largest single contributing factor to the generation of suspended solids in urban areas is construction. In a literature survey of urbanizing areas, Chen (1974) found that soil erosion rates for construction areas ranged from 50 to 200 tons per acre per year.

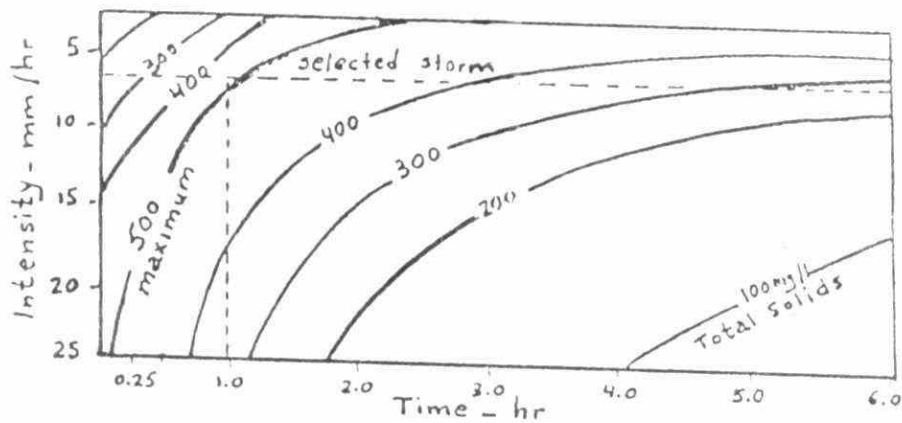


FIGURE 1. TOTAL SOLIDS CONCENTRATION IN RECEIVING WATERS FOR VARIOUS STORMS FOR CASE STUDY

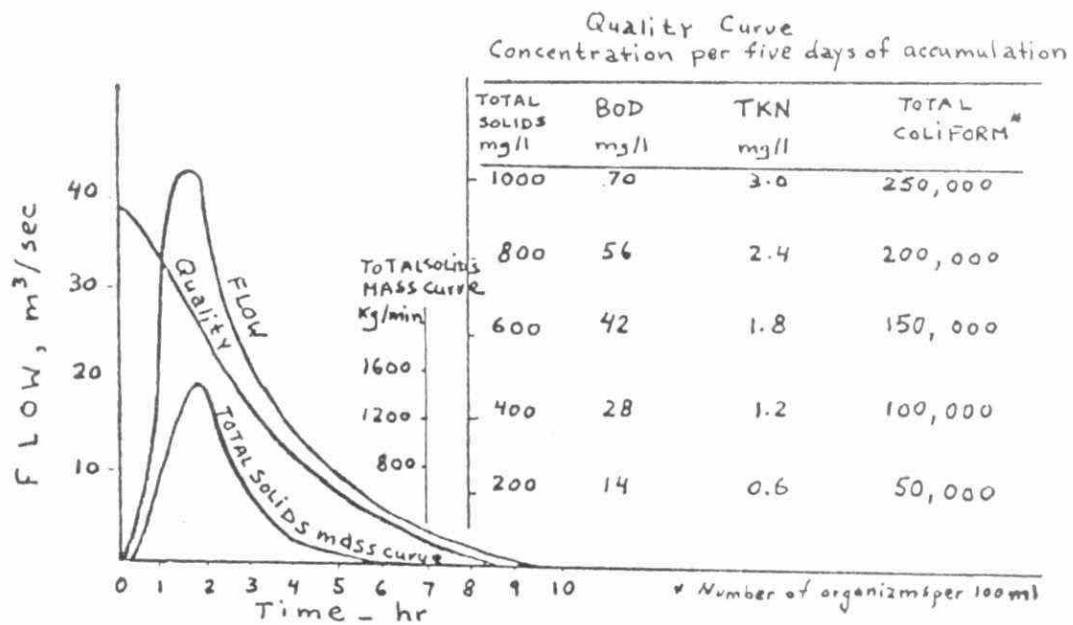


FIGURE 2. QUANTITY HYDROGRAPH FOR CASE STUDY

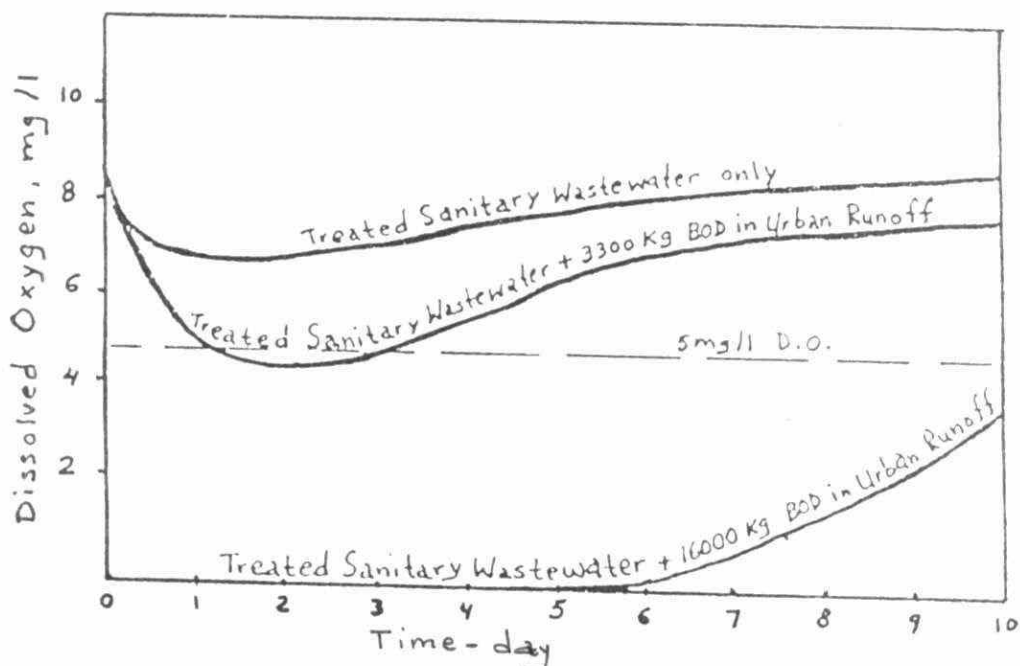


FIGURE 3. OXYGEN SAG CURVES FOR CASE STUDY

Suspended solids are considered as a pollutant for reasons that are less obvious than some other materials which degrade water quality. Suspended solids which find their way into receiving waters may be deposited and become sediment. Sediment is a nuisance if deposited in navigation channels and it can choke drainage ways by reducing their capacity to carry high flows. Sediment can also result in the clogging of gills of fishes and may interfere with spawning or breeding.

High concentrations of suspended solids increase water turbidity and reduce the light penetration of water which might impair certain stream and lake biological systems.

A major impact of suspended solids as a pollutant is related to their ability to serve as a vehicle to carry other pollutants such as heavy metals, pesticides, trace organics, and nutrients into receiving waters (O'Neill, 1979). This role of suspended solids is critical and poorly understood. Little is known why certain materials are soluble or particulate. Research is particularly needed on the adsorption-desorption mechanisms of pesticides, herbicides, trace organics and heavy metals, and the potential threat that attached toxics pose as a result of ingestion by benthic animals.

Nutrients

Nutrient input to receiving waters as a result of urban runoff is a contributing factor to the deterioration of their quality.

Nutrient enrichment may lead to serious problems for aquatic communities. Accelerated eutrophication results in obnoxious algal blooms which may cause taste and odor problems in water supplies, form surface scums in quiescent waters, inhibit swimming and recreation, and may be toxic to small mammals drinking the water. In most inland lakes, and all the Great Lakes, phosphorus is the key element. The level of algal production is directly dependent upon

the amount of phosphorus in a lake. In some forms, phosphorus is immediately available as a nutrient and promotes the growth of algae and other aquatic plants, while other forms of phosphorus may settle to the bottom sediments. While phosphorus in bottom sediments is relatively inert and unavailable as nutrient, it may be reintroduced to lake waters at an accelerated rate when there is an absence of oxygen in the layer of water directly above the bottom sediments (Tanner, 1978).

Waller and Novak (1979) compared the relative contributions to the Great Lakes from the three municipal sources: sewage treatment plants, storm water runoff and combined sewer overflows. They indicated that 20 per cent of the total load from municipal sources of phosphorus originates from storm water runoff and combined sewer overflows.

Data from a study of Mirror Lake in Wisconsin (Knauer, 1975) showed that the lake received approximately 50 per cent of the total annual loading from urban runoff. Shapiro and Pfannkuch (1973) stated that "the chief cause of the increased productivity and subsequent deterioration of the Minneapolis Chain of Lakes is the channeling of storm drainage with its high concentration of algal nutrients to the lakes beginning in the late 1920's."

Kluesener and Lee (1974) concluded that 85 percent of the total phosphorus and 35-40 percent of the total nitrogen input to Lake Wingra (Madison, Wisconsin) were attributable to urban runoff. Konrad et al (1976) reported that event data on the Menomonee River in the Milwaukee Metropolitan area indicate that the concentrations of total phosphorus and total Kjeldahl nitrogen increase during a runoff event; that they generally coincide with changes in the hydrograph; and that the loading during an event may account for a significant fraction of the total baseline loading for the entire month in which the event occurs.

Heavy Metals

Toxic heavy metal loadings from urban areas merit attention as a potential to receiving waters deterioration. These substances are capable of reaching critical levels in quiescent areas where they accumulate in bottom sediments. Heavy metals usually precipitate out of water solution at neutral or alkaline pH, by adsorbing on clay, or by binding to hydrous oxides of iron or manganese (Wilber and Hunter, 1975). Vitale and Sprey (1974) estimated annual loading rates of 100,000-200,000 pounds of lead and 1000-30,000 pounds of mercury from a typical moderate-size city. Pitt and Amy (1973) found that industrial areas have the greatest load and concentration of heavy metals, with commercial areas being the least. As with other pollutants, loadings of heavy metals during storm events have been found to account for a significant portion of the annual load to the stream (Colston 1974; Pitt and Amy 1973; Shaheen 1975; Wilber and Hunter 1975).

There is a particular need for knowledge of the spatial and temporal distributions of heavy metals in the runoff from different types of urban areas. Moreover, because these materials are strongly associated with sediments, much data are needed on the distribution of metals among the various particle sizes of sediment in receiving waters. The information is needed to enable the development of reliable impact assessment techniques and to devise effective control measures.

Bacteria

Microbiological studies of storm water runoff and combined sewer overflows reveal the existence of significant counts of indicator bacteria (total coliforms, fecal coliforms, fecal streptococci), pathogenic bacteria (Pseudomonas aeruginosa, Salmonella sp.), total fungi and parasites.

Burm (1967) indicated that total coliform, fecal coliform and fecal streptococcus densities in the Detroit River increase considerably as a result of overflows from combined sewers.

Burm and Vaughan (1966) made a bacteriological comparison between combined and separate sewer discharges in Southeastern Michigan. They found that the total coliform levels in the runoff from separate storm sewers were about one-tenth of those in combined sewers. The combined sewer discharges contained 40 times as many fecal coliforms as were detected in separate storm runoff. The fecal streptococcus densities, however, were similar in both types of sewer systems and were approximately equal to the fecal coliform counts.

Benzie and Courchaine (1966) reported significantly larger quantities of total coliform, fecal coliforms and fecal streptococci in combined sewer overflows than in storm runoff.

Weibel et al (1966) found that 90 percent of all runoff samples from a separate area contained total coliform, fecal coliform and fecal streptococcus counts exceeding 2900, 500 and 4900 per 100 ml, respectively.

Qureshi (1978) investigated the microbiological characteristics of storm water runoffs at East York (Toronto) and Guelph and found them to contain significant quantities of fecal pollution indicator bacteria. The total coliform densities ranged from 3000 to 1,190,000 per 100 ml. Fecal coliform levels varied from 200 to 560,000 per 100 ml. Fecal streptococci densities were equal to or greater than fecal coliforms and ranged from 3000 to 620,000 per 100 ml.

Microbiological studies of urban runoff have shown consistent recoveries of pathogenic organisms. Evans et al (1968) demonstrated the existence of a potential health hazard by isolating Salmonella thompson (at a level of 4500/100 ml) in a sample taken from a commercial areas served by a separate sewer system.

Qureshi (1978) detected Salmonellae consistently in discharges from the Toronto and Guelph storm sewers. In several instances, these pathogens were readily isolated from as little as 10 ml of storm waters. The salmonella isolates belonged to four different types:

S. haardt, S. saint-paul, S. tennessee and S. typhimurium.

Opportunistic pathogenic bacteria viz. Pseudomonas aeruginosa and Staphylococcus aureus were also isolated from runoffs at both storm sewers. The densities of these two organisms varied from 1 to 630 and 1 to 100 per 100 ml, respectively. In addition, Qureshi found remarkably high population of fungi at both sites. The concentrations fluctuated from 140,000 to 12,000,000 per 100 ml.

Dutka and Rybakowski (1978) investigated the microbiological composition of storm water runoffs in Burlington, Ontario and Brucewood (Toronto). They found that the storm water microbial levels are similar to dilute sewage and contain organisms recognized as health hazards. Among the pathogenic micro-organisms tested for, Pseudomonas aeruginosa were the most numerous and consistently recovered. High concentrations of heterotrophic bacteria and fungi were also present in all storm water samples.

Based on the above evidence one may conclude that the microbial levels in storm water runoff and combined sewer overflows are high and may constitute a health hazard when discharged into a receiving water.

EVALUATION OF ASSESSMENT TECHNIQUES

Assessment techniques of the impact of stormwater runoff and combined sewer overflows on receiving waters range from simple to complex. For the purpose of this memorandum the following four levels of evaluation techniques which are available at the River Systems Unit, Water Resources Branch, MOE, will be considered:

1. Preliminary planning procedures;
2. STORM model coupled with a steady-state dissolved oxygen model;
3. STORM model coupled with a dynamic water quality model; and,
4. SWMM model - a comprehensive dynamic model which provides flow time routing and allows for a continuous receiving water quality impact analysis.

1. Preliminary Planning Procedures

Preliminary planning procedures are based on the methodology used in the report entitled: "Evaluation of the Magnitude and Significance of Pollution Loadings from Urban Stormwater Runoff in Ontario", by Sullivan et.al. (1978). This report was prepared by the American Public Works Association with the assistance of the University of Florida and will be referred to herein as the APWA report.

The APWA report provides an information base on demographic characteristics, land use distribution, drainage systems types, runoff volumes, pollutant loadings on unit area basis, cost and cost effective control strategies for 56 urban areas in Ontario.

The APWA report used the following equation to estimate the per cent of imperviousness in developed portion of urbanized areas:

$$I = 0.096 PD \quad (0.573 - 0.0391 \text{ Log}_{10} PD) \quad (1)$$

where

I = imperviousness in per cent, and
PD = population density in developed portion of the urbanized area, persons per acre.

The equation used to estimate the wet weather flow is:

$$AR = (0.15 + 0.75I)P - 0.5 \quad (2)$$

where

AR = annual runoff, inches
I = imperviousness in per cent, and
P = annual precipitation, inches

The equation used to estimate the dry weather flow is:

$$DWF = 1.45 PD \quad (3)$$

where

DWF = annual dry weather flow, inches per year, and
PD = developed population density, persons per acre.

The annual loading per unit area for various pollutants are calculated as a function of land use, sewer system type, precipitation, population density and street sweeping effectiveness. Table 4 is a summary of the APWA procedure which can be used to obtain a preliminary evaluation of the magnitude and significance of the annual pollution loadings from an urban area. Copies of the APWA report can be obtained from the River Systems Unit, Water Resources Branch.

Singer (1977), in a technical memorandum to PLUARG (Task C) used the APWA procedure to calculate the pollution loadings from urban runoff for the 56 Ontario communities in terms of lbs/acre-month for various land use types and sewer types. The urban land use types and corresponding sewer types which were considered are:

<u>Urban Land Use Type</u>	<u>Sewer Type</u>
1. Residential	Combined
2. Residential	Separate
3. Residential	Unsewered
4. Commercial	Combined
5. Commercial	Separate
6. Commercial	Unsewered
7. Industrial	Combined
8. Industrial	Separate
9. Industrial	Unsewered
10. Other*	Combined
11. Other	Separate
12. Other	Unsewered

* "Other" land use type includes open space, parks, cemeteries, etc.

Table 4. POLLUTANT LOADING FACTORS FOR ONTARIO ASSESSMENT

The following equations may be used to predict annual average loading rates as a function of land use, precipitation and population density.

$$\text{Separate Areas: } M_S = a(i,j) \cdot P \cdot f_2(PD_d) \cdot Y \frac{\text{lb}}{\text{acre-yr}}$$

$$\text{Combined Areas: } M_C = b(i,j) \cdot P \cdot f_2(PD_d) \cdot Y \frac{\text{lb}}{\text{acre-yr}}$$

where M = pounds of pollutant j generated per acre of land use i per year,
 P = annual precipitation, inches per year,
 PD_d = developed population density, persons per acre,
 a, b = factors given in table below,
 Y = street sweeping effectiveness factor, and
 $f_2(PD_d)$ = population density function.

Land Uses: $i = 1$ Residential
 $i = 2$ Commercial
 $i = 3$ Industrial
 $i = 4$ Other Developed, e.g. parks, cemeteries, schools (assume $PD_d=0$)

Pollutants: $j = 1$ BOD₅, Total
 $j = 2$ Suspended Solids (SS)
 $j = 3$ Volatile Solids, Total (VS)
 $j = 4$ Total PO₄ (as PO₄)
 $j = 5$ Total N

Population Function: $i = 1 \quad f_2(PD_d) = 0.142 + 0.218 \cdot PD_d^{0.54}$
 $i = 2, 3 \quad f_2(PD_d) = 1.0$
 $i = 4 \quad f_2(PD_d) = 0.142$

Factors a and b for Equations: Separate factors, a , and combined factors, b , have units lb/acre-in. To convert to kg/ha-cm, multiply by 0.442.

		Pollutant, j				
Land Use, i		1. BOD ₅	2. SS	3. VS	4. PO ₄	5. N
Separate Areas, a	1. Residential	0.799	16.3	9.45	0.0336	0.131
	2. Commercial	2.59	18.0	11.4	0.0612	0.239
	3. Industrial	0.994	23.8	11.8	0.0572	0.226
	4. Other	0.0969	2.31	2.23	0.00852	0.0519
Combined Areas, b	1. Residential	3.29	67.2	38.9	0.139	0.540
	2. Commercial	10.7	74.2	47.0	0.252	0.985
	3. Industrial	4.10	98.1	48.6	0.239	0.931
	4. Other	0.399	9.52	9.19	0.0351	0.214

Street Sweeping: Factor Y is a function of street sweeping interval, N_s , (days):

$$Y = \begin{cases} N_s/20 & \text{if } 0 \leq N_s \leq 20 \text{ days} \\ 1.0 & \text{if } N_s > 20 \text{ days} \end{cases}$$

The monthly pollutant loading estimates were made for suspended solids, volatile solids, five-day biochemical oxygen demand, total phosphorus (as PO_4) and total nitrogen (as N).

The APWA procedure as given in Table 4 was used to calculate the annual pollutant loads in terms of urban land use vs. sewer type. The calculated annual loads were then distributed on a monthly basis by assuming a relationship between monthly loads distribution in a given city and natural streamflow distribution at a gauge near that city.

Waller and Novak (1979) updated the loading estimates in the APWA report to produce estimates of the total load to the Great Lakes from wet and dry-weather municipal sources in Ontario. The two main modifications to the information and procedures in the APWA report were:

1. Surface runoff and sanitary sewage loading estimates are based on concentrations representative of values recorded in Ontario communities; and
2. The methods for calculating combined sewage loadings have been changed to reflect the variability in the composition of combined sewage due to separate input of surface runoff, sanitary sewage and the deposition and scour of solids.

The annual loads of suspended solids, BOD, total nitrogen (as N) and total phosphorus (as P) in sewage treatment plant effluent, surface runoff and combined sewage overflows for 56 cities in Ontario are given in Table 5 (Waller and Novak, 1979).

A copy of the report by Waller and Novak can be obtained from the River Systems Unit, Water Resources Branch.

Table 5.

ESTIMATES OF MUNICIPAL LOADINGS IN ONTARIO

(After Waller and Novak, 1979)

CITY	POPULATION (1000S)	DEVELOPED AREA (1000AC)				ANNUAL LOADS (1000 lb/yr)										
		COMB.	SEP.	UNSEW.	STP	BOD CSO	RNOF	STP	SS CSO	RNOF	STP	N CSO	RNOF	STP	P CSO	RNOF
AJAX	12.52	.16	.49	.84	89.	20.	45.	123.	87.	552.	94.	4.1	11.	5.	.72	1.14
AURORA	11.27	0.00	.82	.86	77.	0.	59.	104.	0.	716.	81.	0.0	15.	5.	0.00	1.47
BARRIE	27.68	0.00	1.51	1.94	197.	0.	120.	266.	0.	1454.	208.	0.0	30.	12.	0.00	2.90
BELLEVILLE	34.74	.81	1.57	1.39	258.	80.	106.	365.	398.	1281.	274.	16.3	26.	15.	2.75	2.64
BRAMPTON	43.64	.08	3.99	0.00	392.	9.	162.	532.	41.	1967.	415.	1.8	41.	23.	.31	4.05
BRANTFORD	64.49	0.00	6.47	0.00	580.	0.	262.	785.	0.	3187.	614.	0.0	66.	34.	0.00	6.56
BURLINGTON	79.64	0.00	6.03	2.66	615.	0.	325.	832.	0.	3943.	651.	0.0	81.	36.	0.00	8.12
CHATHAM	35.69	1.35	2.29	0.00	317.	106.	93.	456.	627.	1131.	337.	22.3	23.	19.	3.52	2.33
CHINGUACOUSY	21.90	0.00	1.74	0.00	197.	0.	71.	267.	0.	857.	209.	0.0	18.	12.	0.00	1.78
COBOURG	11.28	0.00	.61	.79	80.	0.	49.	109.	0.	591.	85.	0.0	12.	5.	0.00	1.22
DUNDAS	17.20	0.00	.88	1.10	125.	0.	69.	169.	0.	835.	132.	0.0	17.	7.	0.00	1.72
ETOBICOKE	280.14	0.00	22.53	1.72	2445.	0.	966.	3308.	0.	11734.	2589.	0.0	242.	144.	0.00	24.16
GALT	38.90	0.00	2.01	2.55	281.	0.	158.	380.	0.	1924.	297.	0.0	40.	17.	0.00	3.96
GEORGETOWN	17.05	0.00	.84	1.04	125.	0.	65.	169.	0.	794.	132.	0.0	16.	7.	0.00	1.64
GUELPH	56.46	0.00	3.31	3.17	414.	0.	230.	559.	0.	2789.	438.	0.0	57.	24.	0.00	5.74
HAMILTON	303.00	17.11	5.40	0.00	2673.	1399.	219.	3958.	8036.	2662.	2842.	293.1	55.	157.	46.93	5.48
KINGSTON	58.42	1.27	3.44	0.00	1527.	129.	140.	1582.	632.	1694.	673.	26.4	35.	30.	4.49	3.49
KITCH-WATER	146.58	0.00	11.15	3.85	1164.	0.	569.	1575.	0.	6907.	1233.	0.0	142.	68.	0.00	14.22
LEAMINGTON	10.44	.13	.39	.65	75.	18.	36.	104.	71.	433.	79.	3.5	9.	4.	.64	.89
LINDSAY	12.75	0.00	.72	.92	90.	0.	57.	121.	0.	695.	95.	0.0	14.	5.	0.00	1.43
LONDON	220.32	3.45	10.35	8.69	1649.	408.	682.	2300.	1792.	8280.	1749.	81.9	170.	97.	14.41	17.49
MARKHAM	16.19	.25	.74	1.23	111.	23.	67.	155.	120.	815.	118.	4.7	17.	7.	.78	1.68
MIDLAND	10.99	.57	.06	.81	222.	44.	27.	247.	264.	326.	98.	9.3	7.	4.	1.47	.67
MISSISSAUGA	148.95	0.00	11.76	3.86	1185.	0.	593.	1603.	0.	7205.	1255.	0.0	148.	70.	0.00	14.83
NEWMARKET	18.95	0.00	1.26	1.45	130.	0.	95.	176.	0.	1149.	137.	0.0	24.	8.	0.00	2.37
NIAGARA FALLS	62.02	3.96	.30	2.53	1344.	286.	86.	1516.	1807.	1074.	595.	60.9	22.	27.	9.36	2.21
NORTH BAY	23.43	.09	1.78	0.00	210.	13.	72.	286.	51.	879.	222.	2.5	18.	12.	.45	1.81
OAKVILLE	54.07	0.00	3.73	2.33	402.	0.	221.	544.	0.	2688.	426.	0.0	55.	24.	0.00	5.53
ORILLIA	26.91	0.00	1.41	1.51	199.	0.	103.	269.	0.	1245.	210.	0.0	26.	12.	0.00	2.56
OSHAWA	92.40	0.00	9.27	0.00	831.	0.	376.	1125.	0.	4568.	880.	0.0	94.	49.	0.00	9.41
OWEN SOUND	18.47	.54	.54	1.37	373.	50.	63.	396.	262.	766.	165.	10.3	16.	7.	1.70	1.58
PETERBOROUGH	57.79	0.00	2.88	3.57	422.	0.	225.	571.	0.	2727.	447.	0.0	56.	25.	0.00	5.62
PICKERING	19.05	0.00	1.05	1.35	135.	0.	83.	183.	0.	1010.	143.	0.0	21.	8.	0.00	2.08
PT. COLBOURNE	17.99	0.00	1.01	1.30	127.	0.	80.	172.	0.	975.	134.	0.0	20.	7.	0.00	2.01

Table 5. (Continued)

CITY	POPULATION	DEVELOPED AREA				ANNUAL LOADS (1000 lb/yr)										
	(1000S)	(1000AC)				BOD		SS				N		P		
		COMB.	SEP.	UNSEW.	STP	CSO	RNOF	STP	CSO	RNOF	STP	CSO	RNOF	STP	CSO	RNOF
PORT ERIE	11.65	.14	.43	.69	84.	20.	38.	117.	79.	462.	90.	4.0	10.	5.	.73	.95
PRESTON	16.72	0.00	.91	1.16	119.	0.	72.	161.	0.	871.	126.	0.0	18.	7.	0.00	1.79
RICHMOND HILL	26.27	0.00	1.62	1.99	182.	0.	126.	246.	0.	1527.	192.	0.0	31.	11.	0.00	3.14
ST. CATHERINES	108.48	5.05	5.93	0.00	964.	381.	241.	1405.	2328.	2921.	1024.	80.7	60.	56.	12.58	6.01
ST. THOMAS	25.54	.94	.31	1.53	183.	90.	59.	267.	459.	714.	195.	18.4	15.	11.	3.08	1.47
SARNIA	56.53	1.06	3.03	0.00	1474.	128.	123.	1520.	557.	1493.	649.	25.8	31.	29.	4.55	3.07
SAULT STE MARIE	70.21	0.00	4.73	3.78	1478.	0.	306.	1478.	0.	3716.	650.	0.0	77.	30.	0.00	7.65
SCARBOROUGH	328.19	5.29	21.16	0.00	2915.	637.	859.	4050.	2764.	10428.	3091.	127.8	215.	171.	22.56	21.47
SIMCOE	10.79	.14	.42	.70	77.	18.	38.	107.	74.	463.	81.	3.6	10.	5.	.64	.95
STRATFORD	24.50	0.00	1.25	1.58	178.	0.	98.	240.	0.	1195.	188.	0.0	25.	10.	0.00	2.46
SUDBURY	89.97	0.00	6.31	5.04	637.	0.	408.	862.	0.	4955.	675.	0.0	102.	37.	0.00	10.20
THUNDER BAY	97.43	2.05	6.16	1.52	2362.	199.	296.	2451.	1007.	3591.	1041.	40.8	74.	47.	6.85	7.39
TORONTO	750.02	17.92	5.97	0.00	6573.	2621.	242.	9251.	9993.	2944.	6973.	517.1	61.	386.	94.67	6.06
TRENTON	14.59	0.00	.71	.87	316.	0.	55.	316.	0.	669.	139.	0.0	14.	6.	0.00	1.38
WALLACEBURG	11.86	.23	.39	.67	86.	27.	36.	121.	120.	436.	91.	5.5	9.	5.	.96	.90
WELLAND	41.71	1.00	1.22	2.83	293.	106.	135.	416.	501.	1635.	311.	21.5	34.	17.	3.70	3.37
WHITBY	16.76	0.00	.92	1.18	119.	0.	73.	161.	0.	885.	126.	0.0	18.	7.	0.00	1.82
WINDSOR	200.37	4.15	9.23	5.76	4588.	449.	548.	4768.	2097.	6656.	2022.	91.0	137.	92.	15.70	13.70
WOODSTOCK	26.17	0.00	1.38	1.76	188.	0.	109.	254.	0.	1327.	199.	0.0	27.	11.	0.00	2.73
YORK	149.44	4.75	.90	0.00	1309.	589.	37.	1856.	2505.	446.	1390.	117.8	9.	77.	20.91	.92
YORK, EAST	106.29	3.20	1.88	0.00	934.	381.	76.	1327.	1664.	925.	991.	76.5	19.	55.	13.47	1.90
YORK, NORTH	499.70	0.00	37.55	0.00	4496.	0.	1524.	6083.	0.	18506.	4760.	0.0	381.	264.	0.00	38.10
TOTALS	4755.	76.	235.	85.	48614.	8228.	12075.	62774.	38335.	146624.	43065.	1668.	3019.	2325.	288.	302.
LOADS (LB/ACRE-YR)					157.	109.	38.	202.	507.	459.	139.	22.	9.	7.	4.	1.
CONCENTRATIONS (MG/L)					20.0	40.7	14.0	25.8	189.8	170.0	17.7	8.3	3.5	1.0	1.4	.35
TOTAL FLOW (IMG/YR)		EFFLUENT:	243051			IN CSO:		20193			IN RUNOFF:	86249				

Table 5. (Continued)

The foregoing results are based on:

Fraction of DWF Solids deposited and scoured = .06
 Values derived from Storm Analysis for Hypothetical Ontario City
 for interceptor capacity of 2.5 times DWF:

Fraction of Hours with Runoff = .108
 Fraction of Annual Sewage in Overflow = .023
 Fraction of Annual Runoff in Overflow = .65
 Per Capita Sewage Flow = 145.
 Comb. Area = 16.2
 Sep. Area = 12.8
 Unsewered Area = 9.5

Concentrations (MG/L)	BOD	SS	TN	TP
in Sewage:	165.00	225.00	30.00	6.50
in primary effluent:	50.00	50.00	22.00	1.00
in secondary effluent:	17.00	23.00	18.00	1.00
In Surface Runoff				
sewered Areas:	14.00	170.00	3.50	.35
unsewered Areas:	14.00	170.00	3.50	.35

LEGEND

STP = Sewage Treatment Plant
 CSO = Combined Sewer Overflows
 RNOF = Storm Water Runoff
 BOD = 5-Day Biochemical Oxygen Demand
 SS = Suspended Solids
 N = Total Nitrogen (As N)
 P = Total Phosphorus (As P)
 COMB = Combined
 SEP = Separate
 UNSEW = Unsewered

2. STORM Model Coupled with a Steady State DO Model

In order to have basic information on the behaviour of receiving waters when subjected to pollutant stresses beyond their existing or natural assimilative capacity, continuous modelling must be applied.

The Storage, Treatment, Overflow and Runoff Model (STORM) was designed to evaluate the quantity and quality of urban runoff. STORM currently enjoys the most extensive use of any urban drainage simulation model. The computer program, model documentation, user's manual and guidelines, are available at the River Systems Unit, Water Resources Branch. STORM (Figure 4), is designed for use with many years of continuous hourly precipitation records but can be used for individual storm events. The model employs an accounting scheme that, for each storm event, allocates runoff volumes to storage and treatment and notes those volumes exceeding storage or treatment capacities. Water quality is handled as a function of hourly runoff rates, with generated quantities of pollutants allocated to storage, treatment or release into receiving waters. Statistics are generated for each event and collectively for all events processed, including average annual values for runoff and pollutant loadings.

The St. Thomas Study (Clarke et al., 1978) is an example of the use of STORM in conjunction with a steady-state model to investigate the impact of urban runoff on a receiving water (Kettle Creek). The STORM model was used to generate pollutant loads from storm and combined sewered areas of St. Thomas during storm events.

Dissolved oxygen was the parameter selected to indicate the water quality impact on Kettle Creek and the Streeter-Phelps equation was used to compute the DO deficit. Figures 5, 6, 7 and 8, show the elements of the Kettle Creek water quality system, the schematic of loadings from St. Thomas, the oxygen balance and the Streeter-Phelps equation used to determine the DO deficit, and the obtained DO deficit for various conditions.

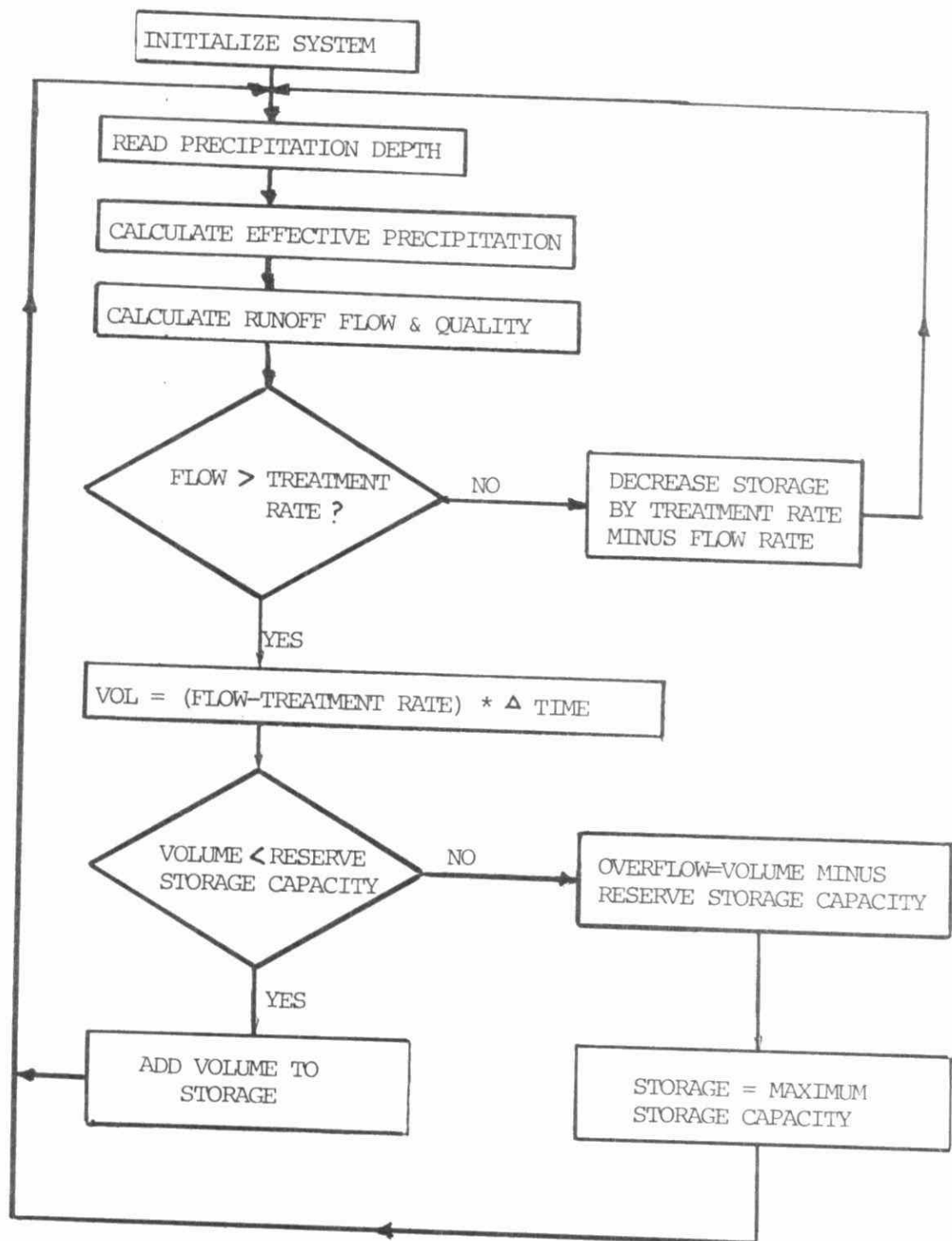
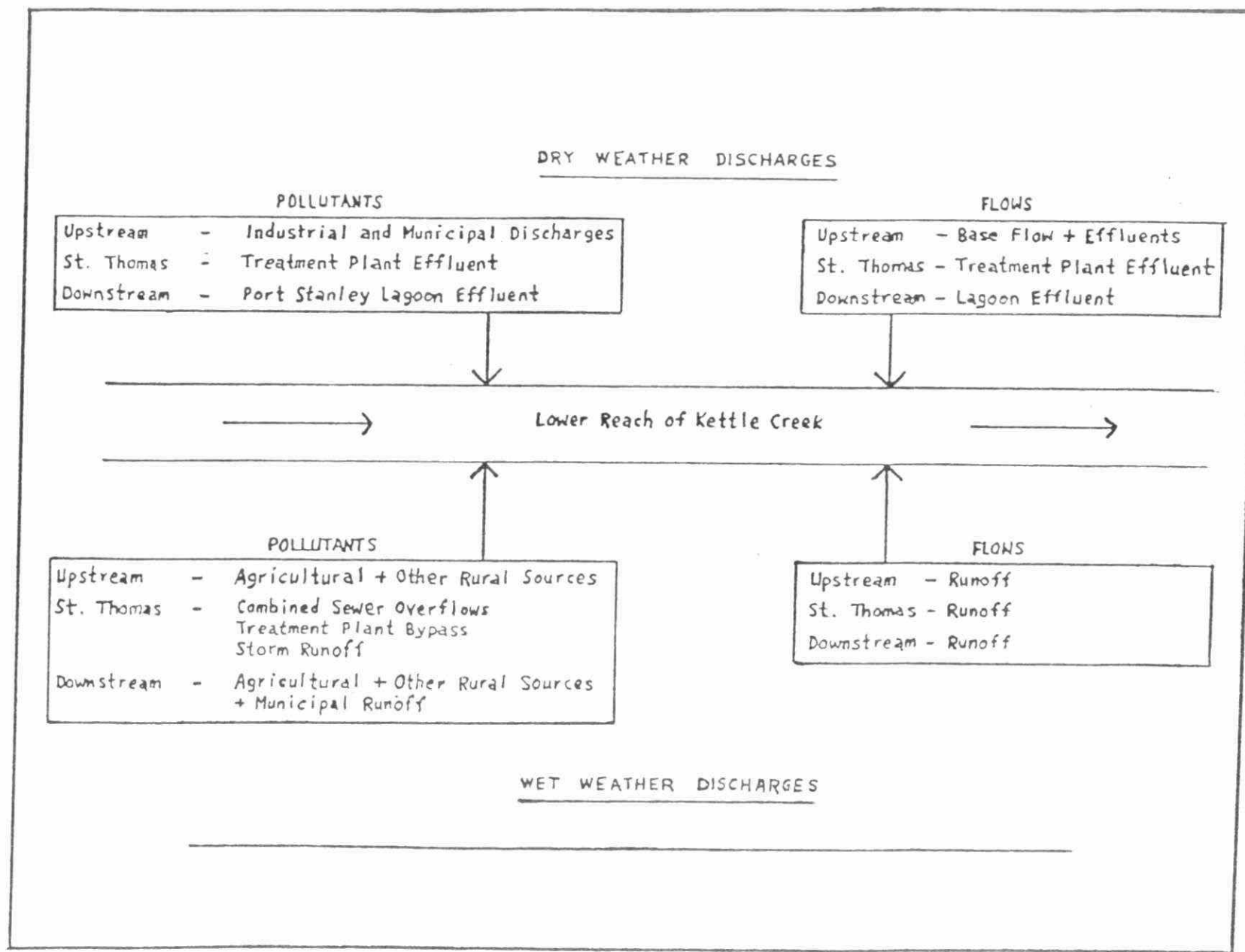


FIGURE 4. "STORM" SIMPLIFIED LOGIC DIAGRAM
(After McPherson, 1979)

FIGURE 5. ELEMENTS OF THE KETTLE CREEK WATER QUALITY SYSTEM (After Clarke et al, 1978)



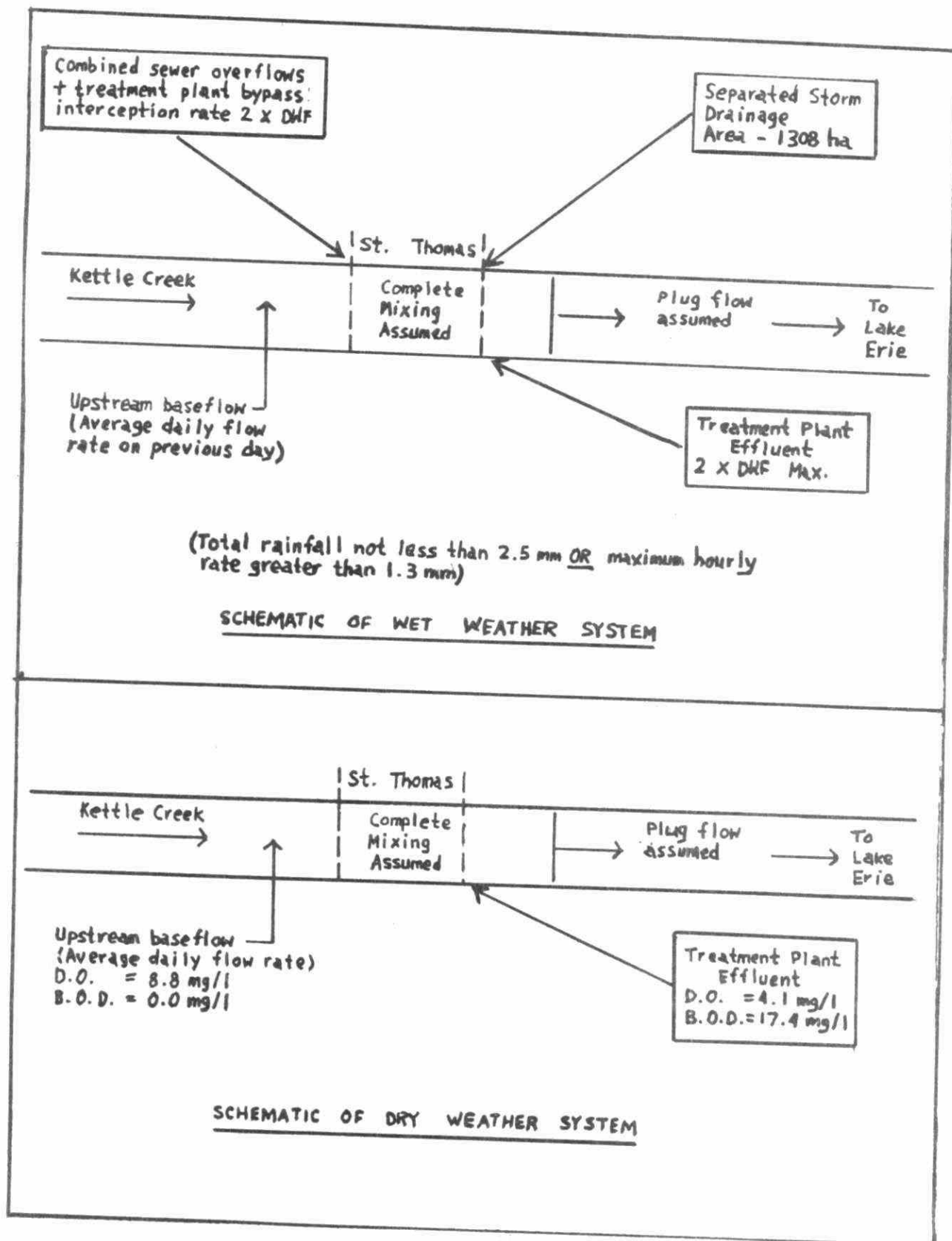
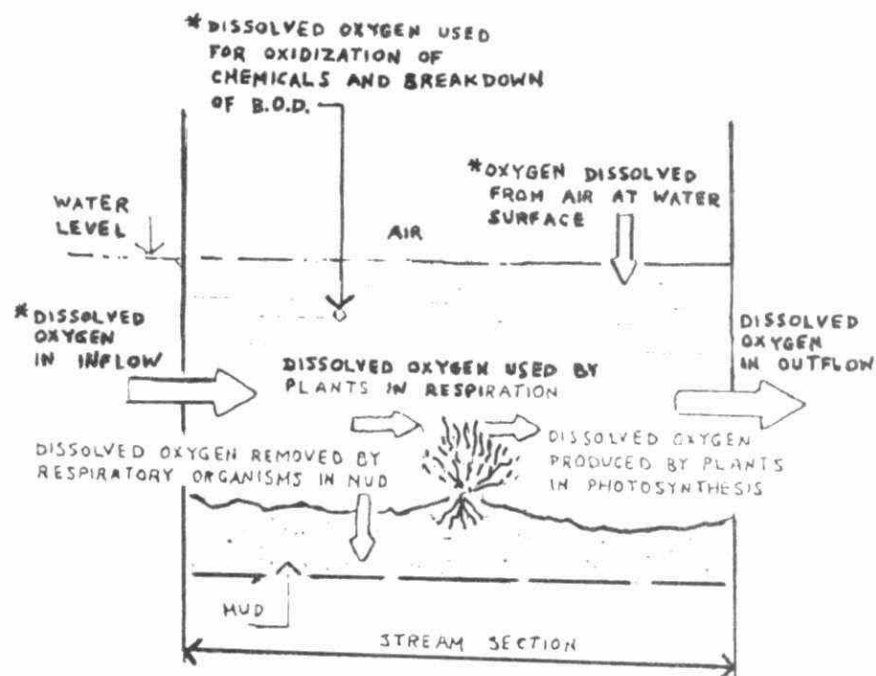


FIGURE 6. SCHEMATIC OF LOADINGS FROM ST. THOMAS
(After Clarke et al, 1978)



STREETER-PHELPS EQUATION

$$\text{D.O. deficit} = \frac{K_d L_a}{K_a - K_d} \left[e^{-K_d t} - e^{-K_a t} \right] + D_a e^{-K_a t}$$

where: K_d = deoxygenation rate constant

K_a = re-oxygenation rate constant

L_a = BOD ultimate in inflow to system (mg/l)

D_a = D.O. deficit in inflow to system (mg/l)

N.B. D_a = saturation concentration - actual concentration

t = travel time (days)

FIGURE 7. OXYGEN BALANCE AND THE STREETER-PHELPS EQUATION (AFTER Clarke et al, 1978)

A similar application was made in Des Moines, Iowa (Sullivan et. al., 1977). The urban runoff and its BOD concentration were obtained from the STORM simulation on an hourly basis. Stream DO's were then simulated using a Streeter-Phelps formulation. Figure 9 illustrates the minimum DO frequency curves for existing conditions in the Des Moines River for various waste inflow combinations. The curves indicate that all combinations including a substantial amount of wet weather flow result in drastic decreases in river minimum DO concentrations. For example, 42 per cent of all the wet weather events throughout the year produced conditions in the receiving water that caused minimum DO levels below 4.0 mg/l. Combined sewers contributed wet weather flow from only 8 per cent of the total urban area modelled, yet the BOD₅ concentration was sufficiently high to inflict an appreciable reduction in DO levels when compared to dry weather flow sources during periods of runoff. A comparison between measured and computed values of DO at 9.0 km downstream from confluence of Raccoon and Des Moines Rivers below the City of Des Moines is given in Figure 10.

3. STORM Model Coupled with a Dynamic Water Quality Model

Output from STORM model can be used also as an input to a dynamic water quality model. Such an application is being carried out currently for the Grand River Basin Water Management Study. The river system being simulated by the dynamic quality model includes eight sewage treatment plants located in Waterloo, Kitchener, Hespeler, Guelph, Preston, Galt, Paris and Brantford. The model considers also urban runoff quality and quantity data produced by STORM on a 2-hourly time step basis. The cities to be simulated by STORM are: Kitchener, Waterloo, Guelph, Brantford and Cambridge (Hespeler, Preston and Galt combined). The upstream flows and upstream water quality constitute boundary conditions for the system.

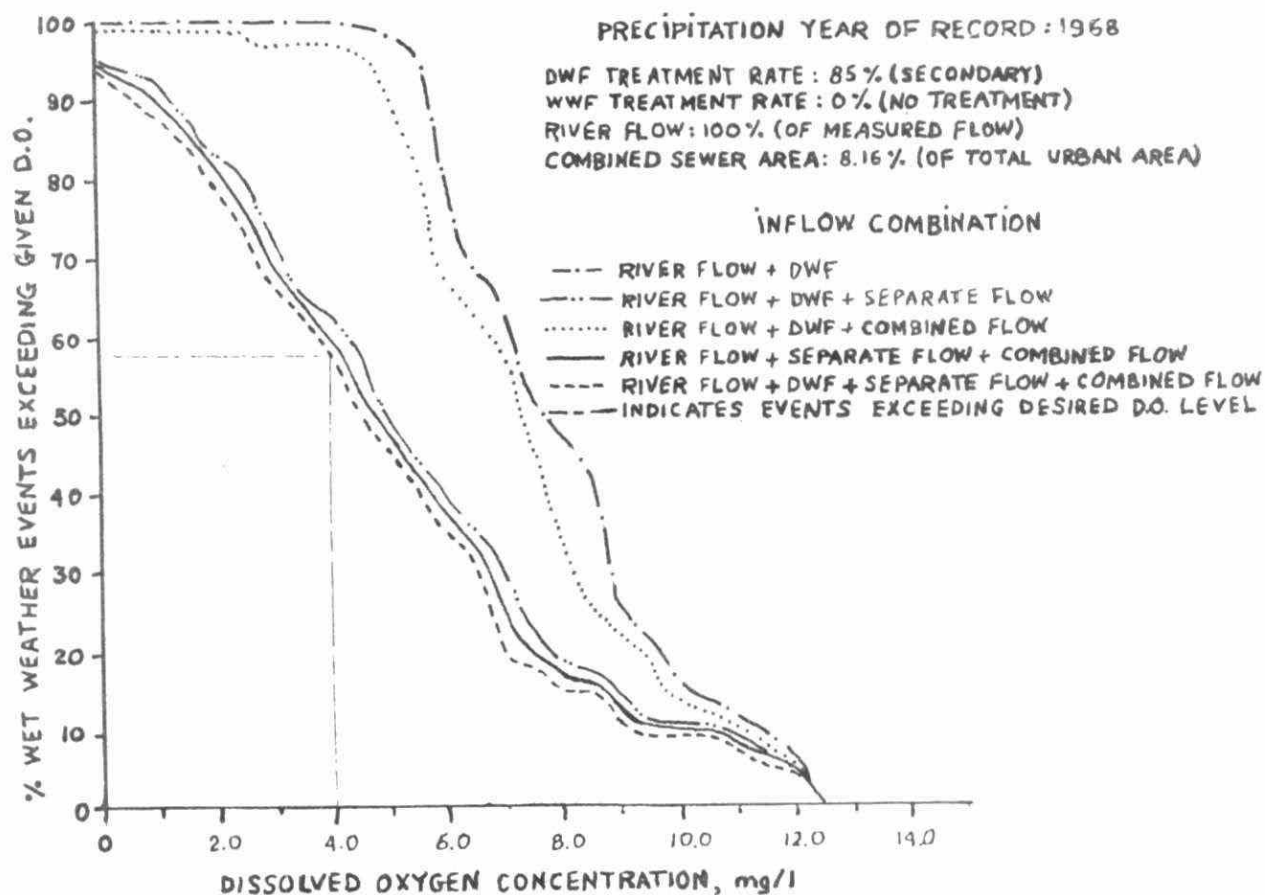


FIGURE 9. MINIMUM DO FREQUENCY CURVES FOR EXISTING CONDITIONS IN THE DES MOINES RIVER (After Sullivan et al, 1977)

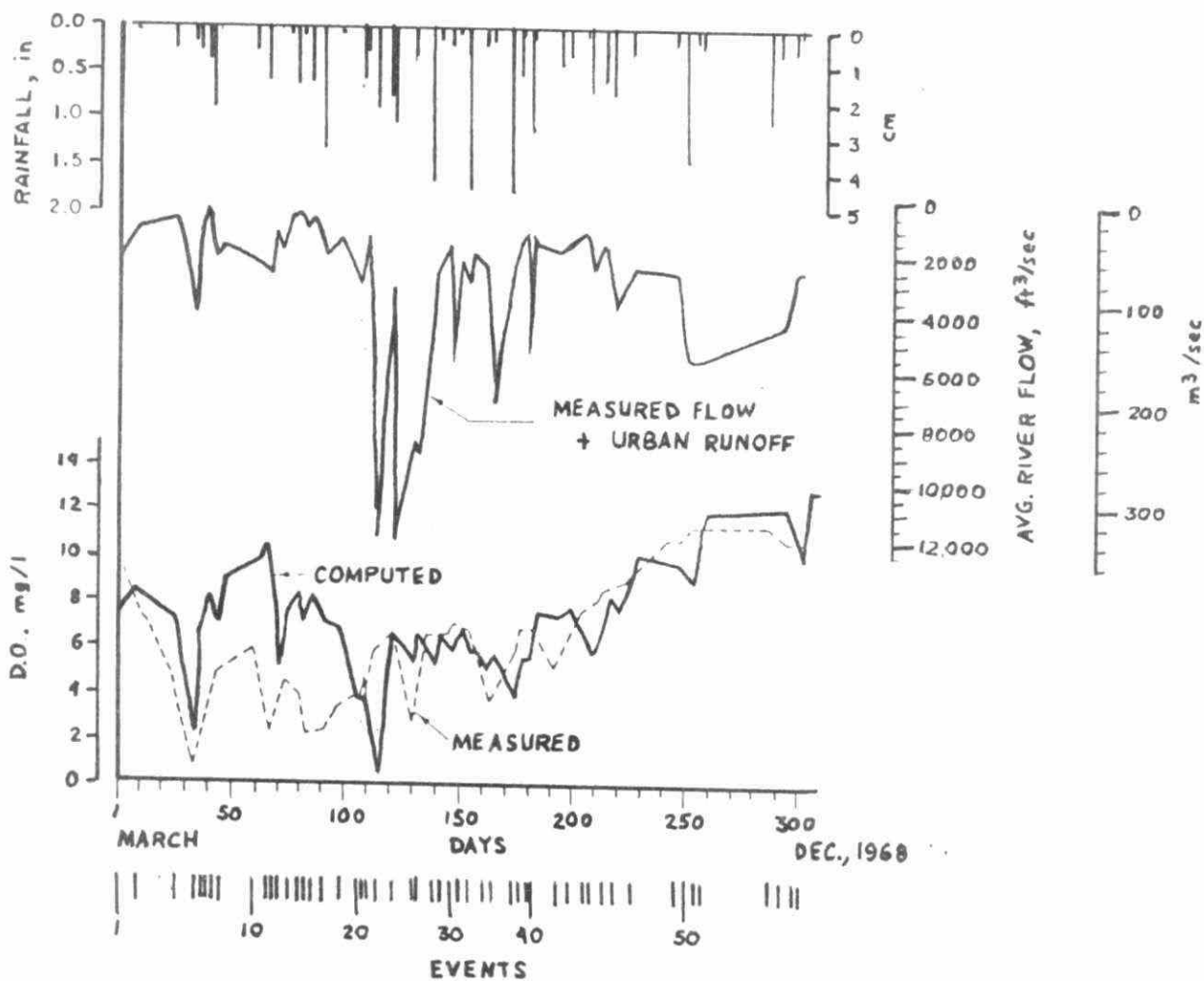


FIGURE 10. APPLICATION TO DES MOINES, IOWA. MEASURED AND COMPUTED VALUES OF DO AT 5.6 mi (9.0 km) DOWNSTREAM FROM CONFLUENCE OF RACCOON AND DES MOINES RIVERS (After Sullivan et al, 1977)

The Grand River Water Quality Model (Figure 11) accepts inputs from sewage treatment plants and storm runoff and routes them through the river system which consists of 20 nodes and 19 reaches. The model computes the river flows and water quality at each node of the system on a 2-hourly time step basis (Kwong et al, 1979). Model runs with and without urban runoff accompanied by probability analyses of water quality violations in terms of DO and unionized free ammonia will reveal the impacts of storm water runoff on the receiver. Model runs with varied dry weather flow treatment alternatives and reduced urban pollution loads will be made to investigate various management options.

4. SWMM Model

The Storm Water Management Model (SWMM) is the most widely used system analysis model in North America. The computer program, model documentation, user's manual and guidelines are available at the River Systems Unit, Water Resources Branch.

A large number of companies and consulting firms in Canada and the U.S. have acquired the SWMM package. Twice per year users meet to exchange experiences in application of SWMM and other models. The SWMM User's Group meetings have become important scientific events open to all interested persons and are supported by the Water Resources Branch, MOE.

SWMM is a comprehensive mathematical model, capable of representing urban storm water runoff (Figure 12). The model accepts any rainfall hyetograph and produces a runoff hydrograph for each modelled urban area. Continuous runoff quality graphs, called pollutographs, are computed on the basis of the volume of storm runoff, antecedent dry period, land use types, street sweeping frequency and sewer type. Real time flow routing is accomplished through a simulation of the physical sewer system.

SWMM consists of a main control and service block - the Executive Block, and four computational blocks: (1) Runoff Block, (2) Transport Block, (3) Storage Block, and (4) Receiving Water Block (Metcalf and Eddy, 1971).

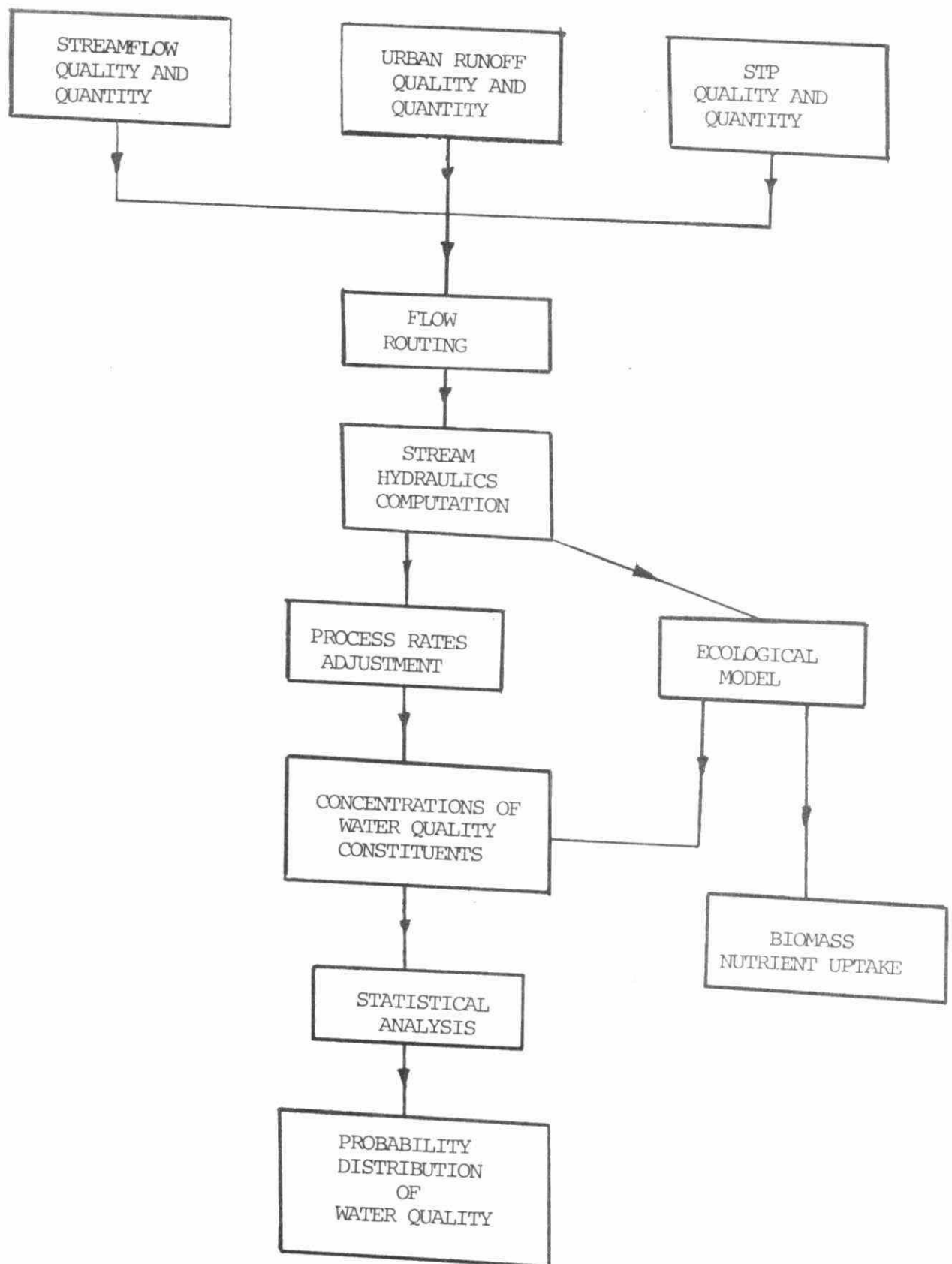


FIGURE 11. GENERAL STRUCTURE OF THE GRAND RIVER WATER QUALITY MODEL (After Kwong et al 1979)

The Executive Block assigns logical units, determines the block or sequence of blocks to be executed, and, on call produces graphs of selected results.

The Runoff Block computes the storm water runoff and its characteristics for a given storm for each subcatchment and stores the results in the form of hydrographs and pollutographs at inlets to the main sewer system.

The Transport Block performs flow and quality routing. It picks up the runoff results and produces combined flow hydrographs and pollutographs for the total urban area.

The Storage Block uses the output of the Transport Block and modifies the flow at a given point according to predefined storage and treatment requirements.

The Receiving Water Block accepts the output of the Transport Block directly, or the modified output of the Storage Block and computes the effects of the urban runoff pollution loads on the receiving river, estuary, lake or bay. The job is done through tracing or routing the pollutants and determining their temporal and spatial variation in the receiving system.

In principle, the capability exists to run all blocks together in a given computer execution. From a practical viewpoint however, typical runs involve one or two computational blocks together with the Executive Block.

Figures 13 and 14 (Metcalf and Eddy, 1971), show an example of the application of SWMM to investigate the impacts of urban runoff from the Kingman Lake drainage basin (Washington, D.C.) on the Anacostia-Potomac Rivers. The rivers were represented by a 47 node system (Figure 13). An appropriate tide was imposed at node 32, fresh water inflows were imposed at nodes 1 and 47, and the Kingman Lake basin discharge was imposed at node 15. The computed oxygen balance in the receiving water system for 5 and 25 hours following the storm of July 22, 1969, is illustrated in Figure 14.

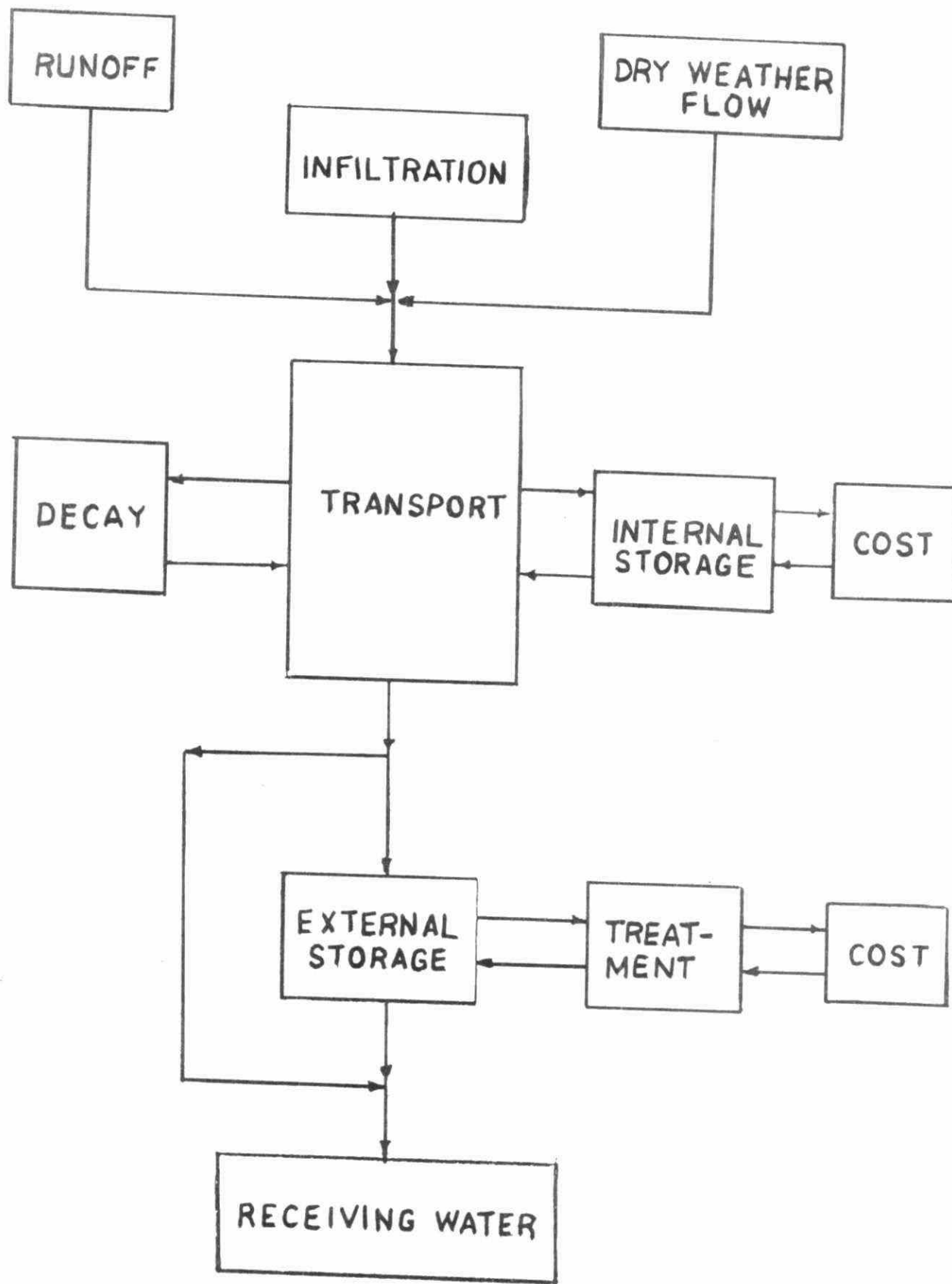


FIGURE 12. SUBROUTINES OF STORMWATER MANAGEMENT MODEL - SWMM (Metcalf & Eddy, 1971)

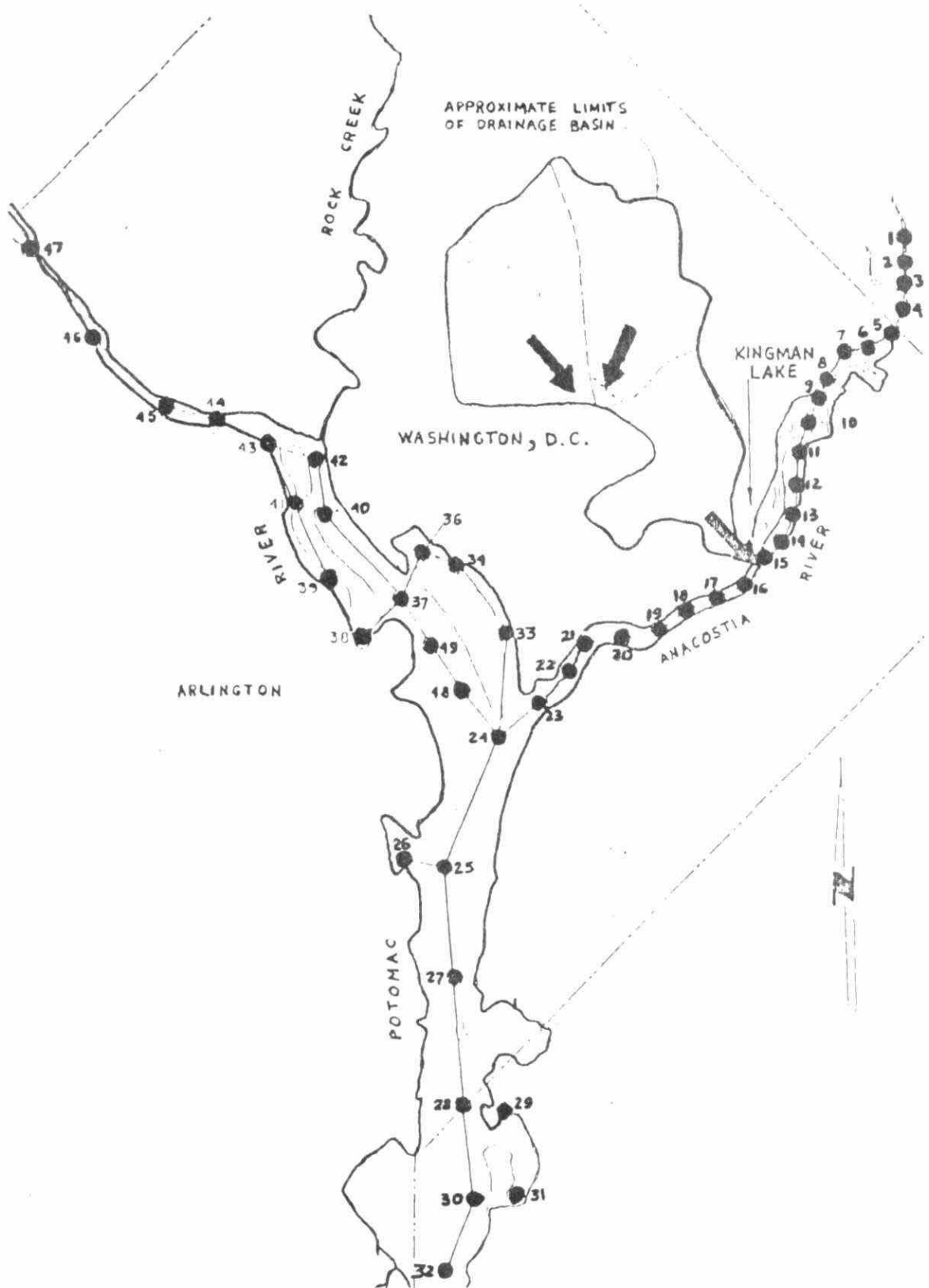


FIGURE 13. KINGMAN LAKE RECEIVING WATER SYSTEM
(After Metcalf & Eddy, 1971)

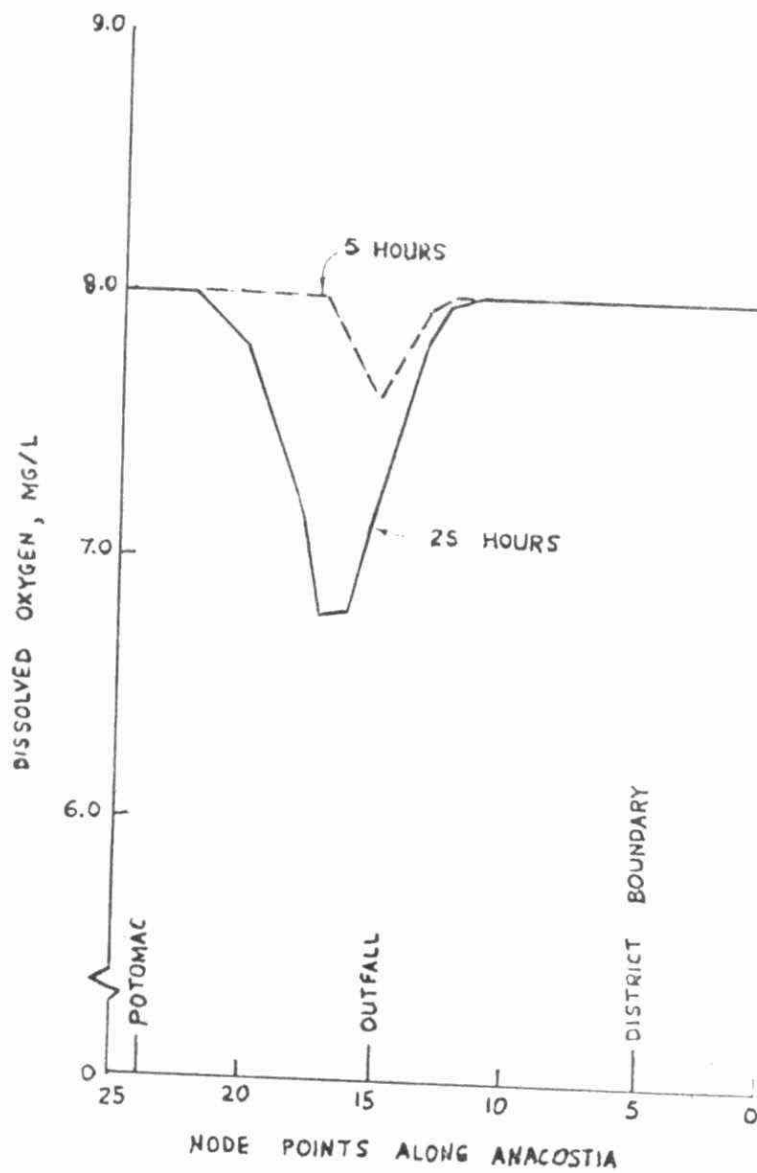


FIGURE 14. KINGMAN LAKE RECEIVING WATER
DISSOLVED OXYGEN PROFILE
(After Metcalf and Eddy, 1971)

CONCLUSIONS

1. Urban surface runoff, either collected separately or coming as nonsewered runoff, and combined sewer overflows will eventually empty into some receiving body of water. These discharges may contribute a significant portion of the total pollution load entering receiving waters on an annual basis, and are often significant on a shock-load basis during wet events (rain and/or snowmelt).
2. The impacts of pollutant loadings carried by stormwater runoff and combined sewer overflows into receiving waters depend on:
 - (a) The type of receiving water (i.e. stream, estuary, bay, lake or ocean);
 - (b) The immediate physical environment surrounding the receiving water (i.e. physiography, climate and runoff);
 - (c) The initial state of the receiving water at the time the waste load is imposed;
 - (e) The amounts and types of pollutants contributed by urban runoff;

Based on the above, it is possible to conclude that the question of impacts of urban runoff on receiving waters is an issue which is affected by local specific conditions. Hence, proper evaluations of these impacts require individual examinations on a city-by-city basis.

3. Assessment techniques of the impacts of stormwater runoff and combined sewer overflows on receiving waters range from simple to complex. The following four levels of assessment techniques are available at the River Systems Unit, Water Resources Branch, MOE:
 - 1 - Preliminary planning procedures;
 - 2 - STORM model coupled with a steady-state dissolved oxygen model;
 - 3 - STORM model coupled with a dynamic water quality model; and,
 - 4 - SWMM model.
4. For a proper choice of the appropriate assessment technique, a precise definition of the problem at hand must be made and the extremely important questions of availability of data, manpower, time and money, must be given due consideration. Staff of the Regional Services of the River Systems Unit are available for consultation and assistance.

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